

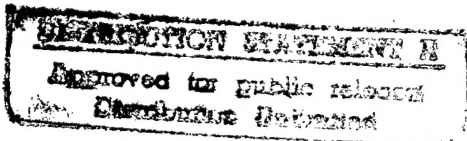
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Simultaneous Independent Parallel Approaches in Canada Using Modernized Sensors and Displays

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MP 95W0000055

June 1995

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MITRE Corporation, McLean, Virginia

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ABSTRACT

Transport Canada has recently completed the Radar Modernisation Programme (RAMP), which was a project to install 22 Terminal Surveillance Radars and 17 Independent Secondary Surveillance Radars, as well as Radar Data Processing Systems and Display Equipment for seven Area Control Centres and two Terminal Control Units. The RAMP Radar and Display System provides a significant increase in surveillance accuracy, display, and processing over earlier radar and display systems. At the request of Transport Canada, the Center for Advanced Aviation System Development (CAASD) at The MITRE Corporation analyzed the RAMP Radar and Display System and Canadian ATC procedures to estimate the potential for refining standards for simultaneous independent parallel ILS approaches. Conclusions are that the system has the potential to allow reduction in minimum runway spacing with some changes to current procedures. Further testing to verify the reduction is recommended, and suggestions for further improvements are included. Analysis and recommendations are also conducted for the Canadian Automated Air Traffic System (CAATS).

ACKNOWLEDGMENTS

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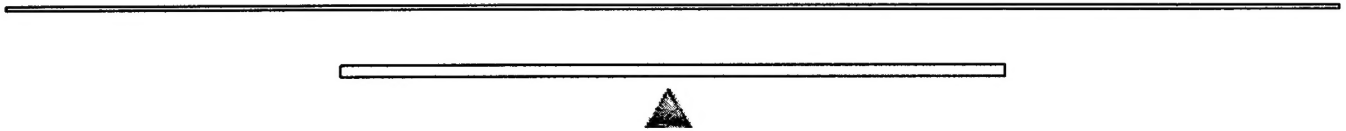
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GLOSSARY

| | |
|--------|---|
| ABD | Anti-Blocking Device |
| ARTS | Automated Radar Terminal Systems |
| ASR | Airport Surveillance Radar |
| ATC | Air Traffic Control |
| ATCRBS | Air Traffic Control Radar Beacon System |
| ATSAMM | Air Traffic Services Administrative and Management Manual |
| CAASD | Center for Advanced Aviation System Development |
| CAATS | Canadian Automated Air Traffic System |
| DSE | Display Equipment |
| FAA | Federal Aviation Administration |
| FAATC | Federal Aviation Administration Technical Center |
| FMA | Final Monitor Aid |
| ICAO | International Civil Aviation Organization |
| ILS | Instrument Landing System |
| MANOPS | Manual of Operations |
| MLS | Microwave Landing System |
| MPAP | FAA Multiple Parallel Approach Program |
| MVA | Minimum Vectoring Altitude |
| NTZ | No Transgression Zone |
| PRM | Precision Runway Monitor |
| PSR | Primary Surveillance Radar |
| RAMP | Radar Modernisation Programme |
| RDPS | Radar Data Processing Systems |
| RSE | Radar Site Equipment |
| SSR | Secondary Surveillance Radar |
| TCAS | Traffic Alert and Collision Avoidance System |
| TNSE | Total Navigation System Error |
| TSR | Terminal Surveillance Radars |





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SECTION 1. INTRODUCTION

1.1 BACKGROUND

Transport Canada has recently completed the Radar Modernisation Programme (RAMP), which was a project to install 22 Terminal Surveillance Radars (TSR) and 17 Independent Secondary Surveillance Radars (SSR), as well as Radar Data Processing Systems (RDPS) and Display Equipment (DSE) for seven Area Control Centres and two Terminal Control Units. The RAMP System provides a significant increase in surveillance accuracy, display, and processing over earlier radar and display systems.

Canadian ATC procedures have permitted simultaneous independent parallel Instrument Landing System (ILS) approaches[1] for a number of years, and several airports conduct these operations routinely. The introduction of the RAMP Radar and Display System will potentially allow Transport Canada to refine the standards for simultaneous independent parallel ILS approaches when the new system is used.

The US Federal Aviation Administration (FAA) has authorized and conducted simultaneous independent parallel ILS approaches for many years. The FAA has also conducted tests of current and new technology equipment with the objective of refining and developing standards for simultaneous independent parallel ILS approaches.

The Center for Advanced Aviation System Development (CAASD) at The MITRE Corporation has conducted basic research into simultaneous independent parallel ILS approaches since the early 1970s, and has assisted the FAA in testing and establishing standards for approaches to two, three, and four parallel runways using a variety of surveillance and display equipment.

Transport Canada requested that CAASD investigate the RAMP Radar and Display System and Canadian ATC procedures to estimate the potential for refining the standards for simultaneous independent parallel ILS approaches. This task is divided into two phases. Phase I involves examination of radar and display system accuracy and ATC procedures to estimate the potential for reduced minimum runway spacing standards for simultaneous independent parallel ILS approaches. If Phase I indicates potential for reduced spacing, a second phase may be conducted. Phase II would involve human factors testing to ensure the adequacy of runway spacing and other standards. At present, only Phase I is being performed.

Transport Canada has also requested an assessment of the effect of the future Canadian Automated Air Traffic System (CAATS) on simultaneous independent parallel ILS approaches. An analysis of the CAATS similar to the analysis of the RAMP Radar and Display System has been conducted.

Neither Phase I nor Phase II address closely spaced simultaneous independent parallel ILS approaches using a high-update-rate sensor.

1.2 ORGANIZATION

The remainder of this section will consist of a short overview of simultaneous independent parallel ILS approaches and the respective standards and equipment used in both Canada and the US. There will also be a summary of the testing and approval process used in the US for new simultaneous independent parallel ILS approach standards. Section 2 contains a summary of significant factors that should be considered when constructing standards. Sections 3 and 4 evaluate and compare Canadian and US equipment and procedures used during simultaneous independent parallel ILS approaches. Section 5 presents an analysis of the effects of Canadian standards and equipment on simultaneous independent parallel ILS approaches. Section 6 provides conclusions and recommendations for further testing. Appendix A contains a summary of US testing for simultaneous independent parallel ILS approaches. Appendix B discusses surveillance system errors, and Appendix C contains an outline of suggested testing for Transport Canada.

1.3 SIMULTANEOUS INDEPENDENT PARALLEL ILS APPROACHES

Simultaneous independent parallel ILS approaches allow controllers to conduct approaches to each runway without explicit consideration of the position of aircraft on the other runways. A minimum of three miles horizontal separation or 1000 ft vertical separation is maintained when aircraft are turned onto their respective courses. A No Transgression Zone (NTZ) at least 2,000 ft wide is established equidistant between runway centerlines. See Figure 1-1. After aircraft are established on their respective courses, aircraft are considered to be safely separated unless an aircraft enters the NTZ. Aircraft approaching one runway may be wingtip to wingtip with aircraft approaching the other parallel runways and may pass or be passed by aircraft on those runways. One or more monitor controllers with radar displays are assigned to observe each approach; also, monitor controllers have a discrete frequency to contact aircraft. In the event of a deviation of an aircraft towards or into the NTZ, monitor controllers must issue evasion instructions to break out aircraft on other approaches in order to prevent a possible collision. A significant deviation towards or into the NTZ will be referred to as a "blunder."

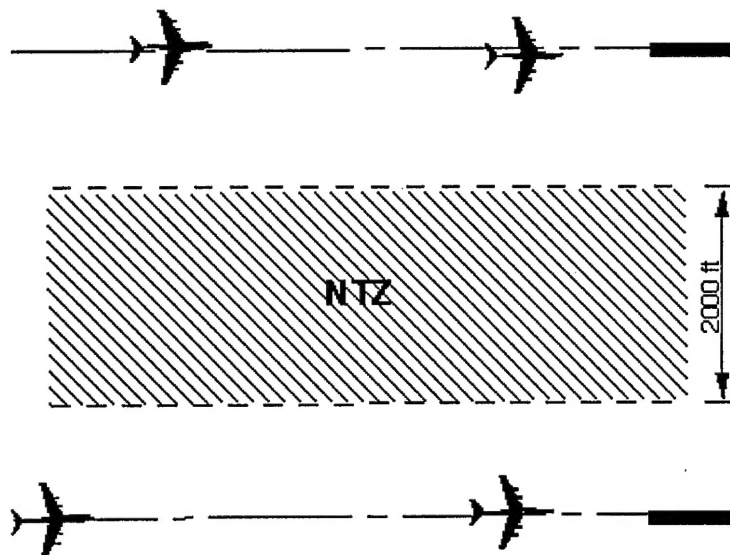


Figure 1-1. Simultaneous Independent Parallel ILS Approaches

Although beyond the scope of this paper, both the US and Canada authorize simultaneous dependent parallel ILS approaches, where aircraft on adjacent approaches are separated by a minimum diagonal separation.

1.4 STANDARDS AND EQUIPMENT FOR SIMULTANEOUS INDEPENDENT PARALLEL ILS APPROACHES

This section provides a brief overview of standards and equipment used or authorized for simultaneous independent parallel ILS approaches. Additional specifics are contained in later sections.

1.4.1 US Standards and Equipment

The US currently authorizes simultaneous independent parallel ILS approaches in the following cases (except as noted, authorizations are in accordance with FAA Order 7110.65 (FAA, 1992a):

- Two runways spaced a minimum of 4300 ft apart when monitor controllers use a conventional sensor and display.
- Two runways spaced a minimum of 3400 ft apart when monitor controllers use a high-update-rate sensor (less than a 2.4 second update interval) and a digital display with alert algorithms.
- Three runways spaced a minimum of 5000 ft apart when monitor controllers use a conventional sensor and display, and the airport elevation is less than 1000 ft above sea level.
- Three runways spaced a minimum of 4300 ft apart when monitor controllers use a conventional sensor and a digital display with alert algorithms, and the airport elevation is less than 1000 ft above sea level.
- Three runways at Denver International Airport (DEN) when monitor controllers use a conventional sensor and a digital display with alert algorithms. DEN's elevation is approximately 5400 ft above sea level; the minimum runway spacing is 5280 feet.

- Three and four runways at Dallas-Fort Worth International Airport (DFW) when monitor controllers use a conventional sensor and display. DFW's elevation is approximately 600 ft above sea level; the minimum runway spacing is 5000 feet. (Authorized by separate waiver letter (Davies, 1990).)

FAA regulations do not specify the conventional sensor.[2] The most common sensor used for simultaneous independent parallel ILS approaches is the ASR-9, a digital radar with an update interval of 4.8 seconds. Other sensors with similar update intervals, such as the ASR-8, are also used. A secondary surveillance radar (SSR) using Air Traffic Control Radar Beacon System (ATCRBS) technology is also employed. The FAA is currently upgrading secondary sensors at many major airports to the Mode S technology, which provides increased SSR accuracy and resolution. A variety of conventional displays are used, typically with an analog presentation of targets using both primary and SSR information. The processing system for the conventional display is the Automated Radar Terminal System (ARTS), and we will use the term "ARTS Display" to indicate a conventional display.

In the late 1980s, the FAA developed the Precision Runway Monitor (PRM) specifically for closely spaced simultaneous independent parallel ILS approaches. The presently fielded version of the PRM is a high-update-rate SSR using monopulse ATCRBS technology. There is no primary sensor input. The electronically scanned antenna has an update interval that can be varied from 0.5 to 5 seconds, although computer processing capacity generally limits the minimum update interval to 1.0 second. The PRM was developed with a 2048 x 2048 color digital display, referred to as the Final Monitor Aid (FMA). This display incorporates a cross-track scale expanded at a ratio of 4.4:1. When an aircraft is projected to enter the NTZ within 10 seconds, the aircraft symbol changes to a yellow color and an aural alert sounds. If an aircraft enters the NTZ, the aircraft symbol changes to red.

The FMA has been adapted to accept information from a conventional sensor. Presently, DEN conducts triple simultaneous independent parallel ILS approaches using an FMA display and a Mode S sensor with a 4.8 second update interval.

1.4.2 Canadian Standards and Equipment

Until recently, Canada had authorized simultaneous independent parallel ILS approaches to two runways spaced a minimum of 4300 ft (1310m) apart using conventional sensors and displays. Transport Canada has recently initiated action to require a minimum separation of 5000 ft (1525m) for such approaches. Recent action has also been initiated to approve simultaneous independent parallel ILS approaches to runways spaced a minimum of 3400 ft (1035m) apart when using a PRM. (Government of Canada Memorandum, 1994).

The RAMP Radar and Display System is the only system within the scope of this study used for simultaneous independent parallel ILS approaches in Canada. The RAMP system has primary and secondary sensors using monopulse ATCRBS technology, together with digital 20 inch diameter monochrome displays. Section 3 contains detailed information on the RAMP Radar and Display System.

The CAATS system will eventually be incorporated with the RAMP sensor into the Canadian Air Traffic Control System. Section 3 also contains detailed information on the CAATS.

1.5 US TESTING OF SIMULTANEOUS INDEPENDENT PARALLEL ILS APPROACHES

To increase airport capacity, the FAA is currently investigating simultaneous ILS approaches to three and four parallel runways and to dual runways with less than 3400 ft of

spacing. As the result of a request to conduct triple and quadruple independent approaches at Dallas/Fort Worth International Airport (DFW), the FAA began a series of real-time simulations at the FAA Technical Center (FAATC) in 1988. The simulations, now performed under the direction of the FAA Multiple Parallel Approach Program (MPAP), are ongoing and have tested a variety of radar sensors, radar displays, runway spacings, and other equipment and procedures for both dual, triple, and quadruple simultaneous independent parallel ILS approaches.

In the FAATC simulations, qualified air traffic controllers use radar displays to provide separation for simulated aircraft conducting simultaneous independent parallel ILS approaches. The aircraft are simulated by rated pilots "flying" advanced cockpit flight simulators or by trained operators, referred to as pseudo pilots, operating specialized computer consoles controlling computer-generated aircraft. In both cases, the pilots or pseudo pilots communicate with the controllers via simulated radio links. The speed, altitude, and heading of the simulated aircraft targets can be altered by simulator pilots or pseudo pilots and the aircraft positions are displayed on each controller's radar monitor. Periodically, the Simulation Test Director, who cannot be observed by controllers, orders a simulated aircraft to deviate (blunder) into another parallel approach course. Controllers must then detect the blunder, attempt to return the blundering aircraft to course, and break out aircraft on adjacent courses that may be threatened by the blunderer.

The FAATC gathers a variety of data on each blunder including trajectories containing the second-by-second longitudinal, lateral, and vertical (xyz) positions of all aircraft; the start time of the blunders; and the time at which the monitor controller responded to the blunder. The principal measure of effectiveness for the simulations is the percentage of blunders that result in a slant range miss distance of less than 500 ft.

Although deviations from course are rare during simultaneous independent parallel ILS approaches, there is evidence that significant deviations do occur; however there is little conclusive information as to frequency and severity of the deviations (Higgins, 1994; Massimini, 1994). The FAA has made assumptions regarding frequency and severity of deviations to allow development and testing and approval of standards (Fain, 1994).

The MPAP uses the results of the simulation to evaluate national standards for multiple simultaneous ILS approaches by conducting statistical analysis and Monte Carlo simulation to estimate the safety of the tested procedure. If the procedure meets a target level of safety (4×10^{-8} collisions per approach) and receives a satisfactory operational assessment from the MPAP members and offices, then the procedure is recommended for adoption.

During the PRM Demonstration Program in the early 1990s, the FAA conducted simulations similar to the MPAP simulations, except that controller and pilot response data were collected separately. These responses were then combined in a Monte Carlo computer simulation to estimate the safety of the procedure. This technique was used to establish the standard for simultaneous independent parallel ILS approaches to two runways spaced 3400 ft apart when using a PRM (FAA, 1991a).

Even without significant deviations, aircraft wander from course during the approach. This wandering is less severe than the deviations discussed above and is due to a number of factors, such as pilot or autopilot technique, winds aloft, tolerances of avionics and ILS equipment, etc. The deviation from the intended course is referred to as Total Navigation System Error (TNSE) and has been measured in field testing (Timoteo and Thomas, 1989; Thomas et. al, 1993).

If an aircraft wanders too close to the NTZ, monitor controllers may have to break out aircraft from the approach. Unlike blunders, deviating aircraft will return to the proper approach course without controller intervention. Such breakouts of wandering aircraft are referred to as "nuisance breakouts" and adversely affect airport arrival rate. The FAA also

evaluates nuisance breakouts and their effect on capacity and controller workload.

The FAA has tested a variety of equipment and airfield combinations using both real-time and Monte Carlo simulation. ARTS displays and ASR-9 sensors, and combinations of FMA displays with ASR-9 and PRM sensors have been evaluated for simultaneous independent parallel ILS approaches to two, three, or four runways. Data and understanding gained from these simulations form the basis for the recommendations contained in this report.

Many of the simulations at the FAATC have involved three runways. In some cases, simulations have been conducted to two and to three runways using the same equipment and airport configuration. During these simulations, there has been negligible difference noted between approaches to two and those to three runways.[3] In this report, we will compare Canadian dual runway approaches with testing done at the FAATC on dual and triple approaches. We believe that such a comparison is reasonable.

See Appendix A for a complete listing of real-time simulations conducted by the MPAP.





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SECTION 2.

SUMMARY OF SIGNIFICANT FACTORS AFFECTING SIMULTANEOUS INDEPENDENT PARALLEL ILS APPROACHES

The major objective in developing standards for simultaneous independent parallel ILS approaches is to determine the minimum spacing between runways. While this is reasonable, extensive analysis and testing (Fabrizi, et al., 1993; Silva and Barrer 1986; Haines and Swedish, 1981) have revealed that the safe execution of simultaneous independent parallel ILS approaches can be dependent upon a number of factors besides runway spacing. The most significant factors are summarized in the paragraphs below including coverage in applicable Canadian, U.S., or ICAO regulations. We separated the factors into four broad categories: Equipment, Training and Human Factors, Procedures, and Facilities. These categories are not mutually exclusive, since several factors relate to one or more categories, but are intended to facilitate the presentation.

Nearly all of these factors are discussed later in this paper. Thus, only rudimentary detail is included in this section. Additional discussion and detail on each of these factors can be found in Fabrizio, et al. (1993).

2.1 EQUIPMENT

This section deals with airport equipment that may significantly affect the controller's ability to separate aircraft in the event of a deviation off course during the final approach. More site-specific items are part of the airfield configuration and design and are covered under Facilities.

2.1.1 Radar System and Location

Numerous studies and simulations (e.g., Haines and Swedish, 1981) have shown the importance of the radar system (display, processors, and sensor) for separating aircraft in the event of a deviation off course. The major areas of the radar system important to simultaneous independent parallel ILS approaches are surveillance delay (including update interval), surveillance system accuracy, automation aids (alarms and display enhancements), and system capacity. Each of these factors is discussed in detail in Section 3.

2.1.2 Communications Equipment and Procedures

Immediately available communication between pilots and controllers is of crucial importance in the safe conduct of simultaneous independent parallel ILS approaches. If one aircraft deviates from course, the controller must immediately break out aircraft on the other approach that might be endangered by the blundering aircraft.

Present Canadian, US, and ICAO standards require that monitor controllers have override capabilities when transmitting. Controllers do not have the capability to override aircraft transmissions, however. There is some concern that conflicting transmissions by pilots and controllers may delay transmission or receipt of controller instructions, increasing the probability of a collision. Such simultaneous transmissions have been observed in testing of simultaneous independent parallel ILS approaches and have been shown to be significant factors in increasing the risk of collision in some scenarios.

2.1.3 Navigation Systems

The imprecision of the aircraft and ground navigation systems used in simultaneous independent parallel ILS approaches can cause aircraft to inadvertently enter the NTZ and thus limit the minimum acceptable separation between parallel approaches. Testing at Los Angeles International Airport (Thomas et. al., 1993) has shown that the magnitude of these errors is not significant at the runway spacing involved in Canada unless aircraft begin descending on the glide slope (and consequently lose 1000 ft vertical separation) far from the airport.

We have assumed that the navigation performance of aircrew and aircraft flying simultaneous independent parallel ILS approaches into Canadian airports is the same as aircrew and aircraft flying into US airports. Although we could not find a specific reference for this assumption, we believe it is reasonable. Similar navigation performance is implicit in ICAO statistical calculations of course deviations that are used in obstacle clearance evaluations. In these calculations, only one statistical distribution of aircraft performance errors is used worldwide (ICAO, 1980).^[4]

2.2 TRAINING AND HUMAN FACTORS

These factors affect the ability of controllers and flight crews to quickly and effectively respond to blunders during parallel approaches.

2.2.1 Air Traffic Control Phraseology

The present ICAO and US standards for simultaneous independent parallel ILS approaches contain detailed phraseology to be used during parallel approaches. Standardized controller phraseology can assist aircrews in understanding and quickly complying with instructions.

2.2.2 Flight Crew Training

The current Canadian, US, and ICAO standards for simultaneous independent parallel ILS approaches do not contain requirements for training or instruction of flight crews flying simultaneous independent parallel approaches. Studies and simulations have shown, however, that flight crew response during blunders is an important factor in reducing collision risk in the event of a deviation from course and that instruction or training of flight crews can affect the speed and quality of their response (Jones, 1992).

2.2.3 Controller Training

Although facilities have a requirement for qualification on each position, including monitor controllers, this training consists primarily of observing and controlling normal operations. Few facilities have training scenarios that require a controller to react to a significant

deviation of an aircraft towards the other course during simultaneous independent parallel ILS approaches, although such training could improve controller response in the event of a blunder.

2.3 AIR TRAFFIC CONTROL PROCEDURES

We have divided the following discussion of various procedures between those primarily associated with approaches where a blunder does not occur, and those procedures needed to respond to such a deviation.

2.3.1 Normal Approaches (Approaches Without Blunders)

This section covers several procedures that are of primary importance to reducing nuisance breakouts.

Aircraft on adjacent approaches maintain at least 1,000 ft of altitude separation until one reaches the glide slope intercept (GSI), where the aircraft begins to descend down the glide slope. If an aircraft strays towards the adjacent approach, but still has at least 1,000 ft of altitude separation, then the procedures do not require controllers to break out the other aircraft. On the other hand, after passing the GSI and losing altitude separation, straying off course can cause a nuisance breakout if the aircraft penetrates the NTZ. Both ILS and Microwave Landing System (MLS) have larger cross-track errors at longer ranges, making navigation errors more likely at long distances from the runway; the Global Navigation Satellite System has errors that are virtually constant with respect to distance from the runway. Thus, if GSI points are far from the runway when using ILS and MLS, there can be more nuisance breakouts. Current standards do not specify maximum distances for GSI when using ILS or MLS.

A large intercept angle between the aircraft and the final approach course can lead to course overshoots and cause the aircraft to take a long time to stabilize on the final approach course. Failure to stabilize before the GSI point could cause nuisance breakouts. Current Canadian, US, and ICAO standards for approaches include restrictions on the maximum intercept angle and the minimum distance between course intercept and the GSI.

Current US and ICAO standards mandate one approach monitor controller per approach, each with a discrete frequency to control their respective aircraft; this requirement allows one monitor controller to instruct a deviating aircraft to return to course while simultaneously the other monitor breaks out aircraft on the adjacent approach.

Divergence of missed approach courses is significant in the event of simultaneous go arounds, such as might occur due to a wind shear alert. Current ICAO, Canadian, and US standards require such procedures.

ICAO, Canadian, and US standards caution personnel to closely monitor weather activity that could adversely impact the final approach course and discontinue approaches if necessary.

2.3.2 Approaches With Significant Deviations

Breakouts that may occur at low altitude during approaches are also of concern, since current obstruction clearance standards for instrument approaches do not include protection for aircraft that may turn off the final approach below the Minimum Vectoring Altitude (MVA).

2.4 AIRPORT FACILITIES

Airport facilities factors include those items of airfield configuration and design that pertain to the conduct of simultaneous independent parallel ILS approaches.

2.4.1 Runway Spacing

The spacing between parallel runways is clearly one of the most important factors in simultaneous independent parallel ILS approaches and is the major emphasis in this report.

2.4.2 Staggered Runway Thresholds

At many airports, the thresholds of parallel runways are not side by side, but are staggered. Computer modeling has shown that staggered thresholds have little effect on the ability of the controller to separate aircraft in the event of a deviation (Fabrizi, et al., 1993). There is some possibility that stagger could slightly improve the rate of nuisance breakouts, but no testing has yet been done. In general, the effect of stagger seems to be minimal.

2.4.3 High Runway Elevation (Density Altitude)

For given facilities and equipment, monitor controllers at airports at higher elevations may have more difficulty separating aircraft in the event of a blunder than controllers at airports near sea level. This is primarily due to the effect of density altitude and the increased true air speeds that aircraft must use to airports with high elevations. Testing (FAA, 1994) has shown that separation of aircraft in the event of a deviation is more difficult for airports with elevations greater than 5,000 ft.

2.4.4 Almost Parallel Approaches

Slightly angling an approach course away from other courses has been shown to decrease the nuisance breakout rate and reduce the chance of collision in the event of a deviation, since this procedure essentially provides increased spacing between approach courses as distance from the runway increases. Such offset approaches should not be necessary at the runway spacings recommended in this report.

2.4.5 Unequal Glide Slope Angles

Simultaneous independent parallel ILS approaches typically have glide slopes with the same descent angle. Testing with computer models has shown that allowing adjacent parallel runways to have differing glide slope angles also provides potential for reducing nuisance breakouts and providing additional separation in the event of a deviation off course. Unfortunately, most jet aircraft are approved for a maximum of a 3.0-degree glide slope, limiting the maximum usable glide slope. Also, increasing the glide slope angle often requires increased landing minima, while reducing the angle may cause difficulties with obstacle clearance on approaches. Unequal glide slope angles should not be a factor for approaches in Canada.





Simultaneous Independent Parallel Approaches in Canada Using Modernized Sensors and Displays

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SECTION 3. RADAR AND DISPLAY SYSTEM FACTORS AFFECTING SIMULTANEOUS INDEPENDENT PARALLEL APPROACHES

The following surveillance system performance factors relevant to monitoring simultaneous independent parallel ILS approaches are discussed in this section:

- Surveillance delay (including surveillance update interval),
- Surveillance system accuracy (combined sensor accuracy and display resolution),
- Surveillance sensor resolution,
- Automation aids (alarms and display enhancements), and
- System capacity.

If the controller display incorporates an aircraft predicted position indicator or a NTZ penetration alarm, as does the FMA, the design and performance of the necessary tracking software and the display presentation are important. Variation in the factors identified above (in combination with the ATC procedures discussed in Section 4.0) contributes towards an appropriate minimum runway separation standard.

Specifications for the RAMP radar and display system (Raytheon Canada Limited, 1986, and Transport Canada, 1990a and b) and the specification for the Canadian Automated Air Traffic System (CAATS) (Hughes Aircraft of Canada, 1993) were reviewed. A comparison is made below with US radar and display systems that are used for parallel approach operations.

3.1 SURVEILLANCE DELAY

Surveillance data delay is the first in a series of delays after a parallel approach blunder occurs before a breakout maneuver begins. The surveillance system contributes a delay in detecting that a blunder has occurred. Additional delays include time needed for communication of a breakout instruction to the pilot and the combined pilot and aircraft response times. The total of all of these delays is a factor limiting the acceptable closeness of runways. Aggregate surveillance system delays accrue from four sources:

- Sensor and display update interval,
- Sensor digital signal processing,

- Data communication (queuing and transmission), and
- Display processing.

3.1.1 Sensor and Display Update Interval

The surveillance sensor and display update interval contributes to the delay in detecting aircraft penetration of the NTZ, and it is also a factor that affects performance of a tracker if one is used in the system. Shorter update intervals reduce delay in detection of NTZ penetration and potentially allow closer runway spacing. Tracker use is discussed in Section 3.3.

The RAMP radar update interval is 4.85 seconds. US radars typically have update intervals of 4.6-4.8 seconds, with the exception of the PRM sensor that has an update interval of 0.5-5.0 seconds. The update interval of the RAMP is similar to that used in simultaneous independent parallel approach simulations that were conducted at the FAATC to gather data to be used as a basis for setting US standards.

3.1.2 Surveillance System Delays

Combined sensor, data communication, and display processing delays are discussed together in this section for various US and Canadian equipment configurations. Table 3-1 summarizes surveillance system delays for different equipment configurations.

ASR-7/8 radars operating with ARTS display have no delay associated with presentation of surveillance video data to monitor controllers. The digital ASR-9 radar introduces a maximum 1.74 seconds of delay to the video ARTS display, and when a Mode S radar is used, the video display delay increases to 2.1 seconds. These delays accrue in the sensor and in the ASR-9 Surveillance and Communications Interface Processor (SCIP) during the process of reconstituting radar video for the ARTS displays. Maximum digital data delays in the ASR-9 and Mode S are 0.48 and 0.78 seconds respectively. Average delays in the digital presentation of ASR-9 and Mode S data on the ARTS are approximately 1 second less; however, the digital data display is not used for parallel approach monitoring.

When using an FMA display, the display delay component must include the digital processing in the ARTS, through which the sensor data passes on the way to the FMA. Data processing delays in the ARTS are 0.3 seconds on average and 0.45 seconds maximum. The FMA adds an average delay of 0.1 seconds and a maximum delay of 0.2 seconds to the total display delay. ASR-9 and Mode S sensors have a communication queuing delay of 0.2 seconds. Mode S is presently interfaced with an FMA at only one location: Denver.

The RAMP radar is specified to have a maximum delay of 120 degrees of antenna rotation. This is equivalent to approximately 1.6 seconds. The average delay was estimated based on the specified maximum delay. The display delays for the RAMP Radar Data Processing System (RDPS) and the CAATS were taken from their respective specifications. The table shows communication queuing delays of 0 seconds because these are judged to be included in the delay specified for the RAMP radar.

TABLE 3-1. SURVEILLANCE SYSTEM DELAYS

| Surveillance Equipment | | Delay Type | Delay Component (sec) | | | |
|------------------------|---------|------------|-----------------------|-------|---------|-------|
| Radar | Display | | Radar | Comm | Display | Total |
| ASR-7/8 | ARTS | max | 0 | 0 | 0 | 0 |
| ASR-9 | ARTS | max | 1.74 | 0 | 0 | 1.74 |
| Mode S | ARTS | max | 2.1 | 0 | 0 | 2.1 |
| ASR-9 | FMA | ave | unkwn | unkwn | 0.4 | unkwn |
| ASR-9 | FMA | max | 0.48 | 0.2 | 0.65 | 1.33 |
| Mode S | FMA | ave | unkwn | unkwn | 0.4 | unkwn |
| Mode S | FMA | max | 0.78 | 0.2 | 0.65 | 1.63 |
| RAMP | RAMP | ave | 0.5 | 0 | 0.5 | 1 |
| RAMP | RAMP | max | 1.6 | 0 | 1.5 | 3.1 |
| RAMP | CAATS | ave | 0.5 | 0 | 0.15 | 0.65 |
| RAMP | CAATS | max | 1.6 | 0 | 0.25 | 1.85 |
| RAMP | FMA | ave | 0.5 | 0 | 0.1 | 0.6 |
| RAMP | FMA | max | 1.6 | 0 | 0.2 | 1.8 |

3.2 SURVEILLANCE SYSTEM ACCURACY

As stated previously, total surveillance system position accuracy is a combination of sensor accuracy and display resolution. This section will discuss sensor position measurement accuracy first, followed by display resolution, and finally total surveillance accuracy.

US air traffic control displays used for parallel approach monitoring show sensor slant-range and azimuth position measurements. Tracked surveillance data is displayed only when a sensor position measurement is unavailable during a particular display update interval. Such track position data is annotated as "coasted" in the associated data block display. The RAMP RDPS specification indicates that the present position symbol is "displayed at the position reported in the associated radar source track message as corrected" (Transport Canada, 1990b). The RDPS converts slant-range to ground-range and adjusts the data to the system display coordinate system (stereographic projection). Radar registration corrections may also be applied, but are said to be not necessary. A complete analysis of the errors introduced when "correcting" the surveillance data in this manner has not been completed at this time. However, the conversion from slant-range introduces an error of approximately 0.1% in range for aircraft on a 3 degree glide slope. The accuracy analysis that follows addresses the azimuth component of sensor error. Slant-range to ground-range corrections should have little effect on this analysis. Radar registration corrections should also have little effect.

In the US, radar monitors used for simultaneous independent parallel ILS approaches rely on a single sensor located proximate to the affected runways. The Canadian RAMP RDPS has the capability to mosaic multiple radars for air traffic controllers. The discussion below assumes that the RAMP RDPS can be configured to enable surveillance by only a single sensor during monitoring of parallel approach operations, thus inhibiting the possibility of displaying surveillance data from a remote sensor with inadequate accuracy.

3.2.1 Sensor Accuracy

The azimuth component of the surveillance sensor accuracy is of principal importance when evaluating the application of a radar system for monitoring simultaneous independent parallel ILS approaches, because parallel operations are affected most by the cross-track component of the total radar error, towards the adjacent approach course. However, the

range accuracy of the radar might also be a concern, depending on the relative locations of the radar and the final approach courses. Typically, the radar is located close to the extension of one of the final approach courses. If the radar is offset far enough from the final approach courses, surveillance range accuracy becomes a significant component of the cross-track error, and must be factored into the analysis. The following analysis of total accuracy addresses situations where the sensor azimuth error component is the principal error component.

The accuracy of the RAMP primary surveillance radar (PSR) is comparable to US airport surveillance radars (ASR), and the accuracy of the RAMP secondary surveillance radar (SSR) is comparable to the US Mode S and PRM radars. These performance characteristics are summarized in Table 3-2. Note that all accuracy data in the table is one standard deviation (1[[sigma]]) with the exception of the RAMP PSR. The RAMP PSR error is specified to be less than the value indicated in the table. ("Error" is undefined in the specifications, but presumably 3[[sigma]] is implied.)

Table 3-2. Radar Performance Factors

| | RAMP PSR | RAMP SSR | ASR-7/8 | ASR-9 | Mode S | PRM |
|-----------------------|----------|------------|------------|------------|------------|------------|
| Update Interval (sec) | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 0.5-5.0 |
| Accuracy | < | 1[[sigma]] | 1[[sigma]] | 1[[sigma]] | 1[[sigma]] | 1[[sigma]] |
| Range (feet) | 911 | 97 | 450/300 | 200 | 25 | 60 |
| Azimuth (deg) | +/-0.5 | 0.05 | 0.18 | 0.16 | 0.06 | 0.057 |

3.2.2 Display Resolution

Display resolution is an important factor in overall surveillance system accuracy. The errors associated with the display of surveillance data and the controllers' interpretation of the displayed data are sub-factors involved in evaluation of the overall surveillance accuracy. Other sub-factors include the scale used in data presentation and the alignment of map overlays used in conjunction with monitoring simultaneous independent parallel ILS approaches. Alignment of maps in all digital systems (FMA, RAMP, CAATS) is not considered to be a problem in comparison with alignment procedures necessary for video maps used in ARTS.

Display and controller interpretation errors were estimated (Matney and Selander, 1986) for an ARTS IIIA display and a postulated *new* display having 1000x1000 pixel resolution and an expanded cross-track scale of 10:1 (this ratio is referred to as the display *aspect ratio*). See Appendix B for an excerpt from this report. Expansion of the cross-track display scale increases lateral resolution of aircraft position data, improving detection of aircraft movement towards the NTZ. This provides increased ability for monitoring simultaneous independent parallel ILS approaches. ARTS display error is estimated at 0.23 degrees[5] and controller interpretation error at 0.07 degrees. The *new* display and controller interpretation errors are estimated at 0.003 and 0.01 degrees respectively.

The introduction of high resolution digital displays (with the FMA) provides a very significant factor in the improvement of overall surveillance accuracy. The FMA display resolution is specified at 2048x2048; the system is implemented at Denver and was tested at the FAATC with a 4.4:1 display aspect ratio. Display and controller interpretation errors vary depending on the range scale selected for monitoring approaches. Cross-track resolution varies with along-track range because the 4.4:1 aspect ratio is fixed. Values for display and controller interpretation errors are listed in Table 3-3 for along-track ranges that were tested at the FAATC.

The RAMP and CAATS displays, with resolutions specified at 2000x2000 and 2048x2048

respectively, compare favorably with the FMA display. However, these displays do not have the capability to display surveillance data with an expanded cross-track scale.

3.2.3 Total Surveillance Accuracy

The total surveillance accuracy is determined by combining the component errors by the root-sum-square method. Tables 3-3 and 3-4 show the total surveillance accuracy for various US and Canadian equipment configurations respectively, and for various along-track display ranges. The data are grouped by display type. Along-track ranges were analyzed for US tested and actual parallel runway monitoring configurations. Configurations tested at the FAA Technical Center are shaded in gray. Mode S sensor configurations were computed with and without the bias component of the specified Mode S sensor accuracy.

Table 3-4 lists multiple configurations of the RAMP radar with RAMP, CAATS, and FMA display alternatives. RAMP and CAATS display ranges must be set at 20 nmi to conduct independent parallel approach monitoring to enable monitoring to the expected range of 18 nmi where aircraft are turned on to final. The table lists an 18 nmi alternative range scale to show the total surveillance system accuracy improvement that is possible if these display systems were modified to allow that range scale setting. Additionally, the table shows hypothetical 4.4:1 aspect ratio display configurations for the RAMP and CAATS displays as an example of the improvement that could be possible with software changes to enable this capability.

The tables show that all configurations of Canadian hardware provide total surveillance accuracy that is better than the accuracy of the systems that were tested at the FAA Technical Center.

Table 3-3. Total Surveillance System Accuracy for US Equipment Configurations

| Surveillance Equipment | | | | Surveillance Accuracy 1 Sigma Error | | | |
|------------------------|---------|-----------------------|--------------------------|--|------------------|---------------------------------------|-------------------------|
| Radar | Display | | | Radar (deg) | Display (deg) | Controller Interpretation (deg) | Total (rms) (deg) |
| | Type | Max Range (nmi) | Aspect Ratio (x:1) | | | | |
| ASR-7/8 | ARTS | 20 | 1 | 0.18 | 0.23 | 0.07 | 0.300 |
| ASR-9 | ARTS | 20 | 1 | 0.16 | 0.23 | 0.07 | 0.289 |
| Simulated ASR-9 | ARTS | 20 | 1 | 0.115 | 0.23 | 0.07 | 0.266 |
| Mode S w/ bias | ARTS | 20 | 1 | 0.068 | 0.23 | 0.07 | 0.250 |
| Mode S w/o bias | ARTS | 20 | 1 | 0.06 | 0.23 | 0.07 | 0.248 |
| ASR-9 | New | 16.5 | 10 | 0.16 | 0.003 | 0.01 | 0.160 |
| Mode S w/ bias | New | 16.5 | 10 | 0.068 | 0.003 | 0.01 | 0.069 |
| Mode S w/o bias | New | 16.5 | 10 | 0.06 | 0.003 | 0.01 | 0.061 |
| ASR-9 | FMA | 22 | 4.4 | 0.16 | 0.004 | 0.015 | 0.161 |
| ASR-9 | FMA | 18 | 4.4 | 0.16 | 0.004 | 0.012 | 0.161 |
| Simulated ASR-9 | FMA | 22 | 4.4 | 0.115 | 0.004 | 0.015 | 0.116 |
| Simulated ASR-9 | FMA | 18 | 4.4 | 0.115 | 0.004 | 0.012 | 0.115 |
| Mode S w/ bias | FMA | 18 | 4.4 | 0.068 | 0.004 | 0.012 | 0.069 |
| Mode S w/o bias | FMA | 18 | 4.4 | 0.06 | 0.004 | 0.012 | 0.061 |

Notes: Display and controller interpretation errors for all displays except ARTS are

expressed as equivalent degrees for a range of 10 nmi. Shaded configurations were tested at the FAA Technical Center.

Table 3-4. Total Surveillance System Accuracy For Canadian Equipment Configurations

| Surveillance Equipment | | | | Surveillance Accuracy 1 Sigma Error | | | |
|------------------------|---------|-----------------------|--------------------------|--|------------------|---------------------------------------|-------------------------|
| Radar | Display | | | Radar (deg) | Display (deg) | Controller Interpretation (deg) | Total (rms) (deg) |
| | Type | Max Range (nmi) | Aspect Ratio (x:1) | | | | |
| RAMP SSR (spec) | RAMP | 20 | 1 | 0.07 | 0.018 | 0.061 | 0.094 |
| RAMP SSR (spec) | RAMP | 18 | 1 | 0.07 | 0.016 | 0.055 | 0.090 |
| RAMP SSR (spec) | RAMP | 20 | 4.4 | 0.07 | 0.004 | 0.014 | 0.071 |
| RAMP SSR (spec) | RAMP | 18 | 4.4 | 0.07 | 0.004 | 0.012 | 0.071 |
| RAMP SSR (test) | RAMP | 20 | 1 | 0.05 | 0.018 | 0.061 | 0.081 |
| RAMP SSR (test) | RAMP | 18 | 1 | 0.05 | 0.016 | 0.055 | 0.076 |
| RAMP SSR (test) | RAMP | 20 | 4.4 | 0.05 | 0.004 | 0.014 | 0.052 |
| RAMP SSR (test) | RAMP | 18 | 4.4 | 0.05 | 0.004 | 0.012 | 0.052 |
| RAMP SSR (spec) | CAATS | 20 | 1 | 0.07 | 0.018 | 0.059 | 0.093 |
| RAMP SSR (spec) | CAATS | 18 | 1 | 0.07 | 0.016 | 0.053 | 0.089 |
| RAMP SSR (spec) | CAATS | 20 | 4.4 | 0.07 | 0.004 | 0.013 | 0.071 |
| RAMP SSR (spec) | CAATS | 18 | 4.4 | 0.07 | 0.004 | 0.012 | 0.071 |
| RAMP SSR (test) | CAATS | 20 | 1 | 0.05 | 0.018 | 0.059 | 0.080 |
| RAMP SSR (test) | CAATS | 18 | 1 | 0.05 | 0.016 | 0.053 | 0.075 |
| RAMP SSR (test) | CAATS | 20 | 4.4 | 0.05 | 0.004 | 0.013 | 0.052 |
| RAMP SSR (test) | CAATS | 18 | 4.4 | 0.05 | 0.004 | 0.012 | 0.052 |
| RAMP SSR (spec) | FMA | 20 | 4.4 | 0.07 | 0.004 | 0.013 | 0.071 |
| RAMP SSR (test) | FMA | 20 | 4.4 | 0.05 | 0.004 | 0.013 | 0.052 |

Note: Display and controller interpretation errors are expressed as equivalent degrees for a range of 10 nmi.

3.3 SENSOR RESOLUTION

Sensor resolution is a factor in a system for monitoring simultaneous independent parallel ILS approaches. The system must be able to resolve aircraft that may drift close to the NTZ after the aircraft lose altitude separation. Primary radars have very good range resolution, often equivalent to twice the range accuracy. Primary radar azimuth resolution is approximately 1.75 times the beamwidth. As a practical matter, it is difficult to measure the azimuth resolution of a radar in a test situation because the test aircraft is often resolved in range before azimuth. Conventional SSRs suffer from synchronous garble whenever aircraft are simultaneously within the main beam of the antenna and separated in range by less than 1.6 nmi. Whenever this occurs, surveillance data on one or both aircraft are lost or sometimes erroneous. Monopulse SSRs do not suffer from this problem if designed properly.

The ASR-9 is specified to have a range resolution of 760 feet and an azimuth resolution of approximately 3.4 and 2.86 degrees (at 10 and 40 nmi respectively). At a range of 10 nmi,

the ASR-9's azimuth resolution is approximately 3645 feet or 0.6 nmi. At this range, the sensor cannot resolve (in azimuth) two aircraft that are each close to the boundary of a 2000 ft NTZ (assuming a typical radar location on the airport between the runways). However, it is unlikely that the aircraft will not resolve in range.

The RAMP monopulse SSR is specified to have range resolution of 303.8 ft and azimuth resolution of 2.4 degrees. This is better than the ASR-9, but still leaves two aircraft that are at exactly 10 nmi range unresolvable if separated by less than 2545 feet. At a range of 15 nmi the azimuth resolution is 3818 feet. (Once again, however, it is unlikely that the aircraft will not resolve in range.)

The RAMP SSR actually performs better in azimuth resolution than required by the specification. The current design is an improvement, and the typical azimuth resolution performance is stated to be 0.6 degrees (Stevens, 1988). With azimuth resolution better than 0.6 degrees, there should be no problem providing surveillance data for monitoring simultaneous independent parallel ILS approaches with the RAMP SSR.

3.4 AUTOMATION AIDS

The FMA incorporates a 10 second predicted position indication on the display as an aid to parallel approach monitoring. Additionally, the FMA provides a warning when the predicted position enters the NTZ and an alert when the sensor position measurement falls within the NTZ. The display technique for the predicted position uses a line from the last sensor position measurement, in the direction of the tracked velocity estimate, with a length calculated from the tracked speed estimate.

The FMA implements an alpha-beta tracker with $[\alpha]=0.72$ and $[\beta]=1.0$ for 4.8 second update interval operation. Lower values for $[\alpha]$ and $[\beta]$ provide increased smoothing, consequently, there is little velocity smoothing as compared with typical ATC trackers. With the low level of smoothing implied by these parameters, the predicted position shown on the display will be very responsive to maneuvers of the tracked aircraft. ARTS uses an adaptive alpha-beta tracker that varies the smoothing for tracks depending on how well the predicted position correlates with the radar measurement. Different values are used for $[\alpha]$ and $[\beta]$ to smooth the track longitudinally and laterally (with respect to the track velocity). This accounts for the expected dynamics of an aircraft. In general, the ARTS tracking process smoothes the track much more than the FMA. Values for $[\alpha]$ are less than 0.72 except for very poor or new tracks and values for $[\beta]$ are always less than 0.89 and rapidly fall below 0.1 as track quality improves.

RAMP and CAATS have predicted track line capability for future time periods of 1-20 minutes (default 3). The RAMP RDPS tracker is similar to the ARTS tracker with higher smoothing in both position and velocity than the FMA tracker. The RAMP RDPS tracker values for $[\alpha]$ decrease from 0.833 to 0.464 as the track becomes firmer; and values for $[\beta]$ are always less than 0.5. To achieve automation aid capabilities similar to those of the FMA, the RAMP RDPS tracker would require modification.

3.5 CAPACITY

The radar and display processing systems must have the capacity to provide surveillance for all aircraft on simultaneous independent parallel ILS approaches. The RAMP Radar and Display System should have adequate capacity to meet this requirement. Limitations on the length of the final approach course may be necessary due to the RAMP SSR capacity limitation of 14 aircraft per 2.45 degrees (azimuth with reference to the radar location). By comparison, Mode S is specified to have a capacity of 32 aircraft per 2.4 degrees.





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SECTION 4. EVALUATION OF CANADIAN PROCEDURES FOR SIMULTANEOUS INDEPENDENT PARALLEL ILS APPROACHES

A detailed investigation of the Air Traffic Control Manual of Operations (MANOPS) (Transport Canada, 1993) and the Air Traffic Services Administrative and Management Manual (ATSAMM) (Transport Canada, 1992) was performed, and procedures contained in these manuals were evaluated with respect to the significant factors affecting simultaneous independent parallel ILS approaches. Current ICAO and US FAA procedures were also compared with Canadian procedures. Additionally, simultaneous independent parallel ILS approach procedures were discussed with Canadian controllers and supervisors during a visit to Toronto Air Control Center.

In general, Canadian procedures for simultaneous independent parallel ILS approaches are satisfactory and are similar to US procedures. The general readability of the standards is to be commended. Several areas, such as specification of phase-in requirements for new procedures or equipment, are absent from US and ICAO standards and are also commendable.

Some modifications to Canadian procedures will be necessary if simultaneous independent parallel ILS approaches are to be run at the minimum runway spacings suggested in this paper. Areas of significant concern and conflicting procedures are discussed below. These concerns are based on observations and testing of simultaneous independent parallel ILS approaches for a number of years, and not necessarily on differences between Canadian, ICAO, or US standards. Indeed, many of the concerns mentioned below are common to all three.

4.1 AREAS OF SIGNIFICANT CONCERN

Canadian ATC procedures require only one controller to monitor simultaneous independent parallel ILS approaches to two runways. US and ICAO procedures require one controller for each runway, with a separate frequency for each controller to talk to aircraft on the respective approach (ICAO, 1985; FAA, 1992a). The use of only one monitor controller has several disadvantages in the event one aircraft should deviate from course towards the other parallel approach course.

First, in the event of a deviation by one aircraft, two monitor controllers on separate frequencies can simultaneously instruct the deviating aircraft to return to course and break out any threatened aircraft. Canadian procedures require the monitor controller to first break out the threatened aircraft and then attempt to return the deviating aircraft to course. Extensive testing of simultaneous independent parallel ILS approaches in the US has shown that when transmissions are made simultaneously and both aircraft respond promptly, the chance of a collision is negligible. If the deviating aircraft does not respond promptly, however, the chance of a collision increases. The present Canadian procedures may result in a slower response by the deviating aircraft, increasing collision risk.

A second consideration when using one monitor controller is the increased chance that break-out instructions might be blocked by simultaneous transmissions. If an aircraft were to deviate from one course due to an emergency and transmit this information to the controller, the controller may be blocked from promptly transmitting evasion instructions to aircraft on the other approach course. Simultaneous transmissions are frequently experienced during testing of simultaneous independent parallel ILS approaches when using two monitor controllers and frequencies. Use of only one controller would be expected to exacerbate the difficulties.

We strongly recommend that Canadian procedures for simultaneous independent parallel ILS approaches be modified to require that one monitor controller be used for each runway.[6] Each monitor controller should have a separate discrete frequency with tower-override capability.

Another area that may need to be addressed stems from the fact that the RAMP Radar and Display System is capable of displaying position information from more than one sensor to the controller. Often the other sensors can be a considerable distance from the airport. While such a capability is highly desirable for most operations, the degradation of position accuracy associated with use of a sensor at a distance from the airport is generally undesirable during simultaneous independent parallel ILS approaches. In Section 3 we discuss the generally superior accuracy of the RAMP Radar and Display System, but this accuracy is dependent on the sensor placement at the airfield conducting the simultaneous independent parallel ILS approaches (and generally between the parallel runways). Use of a radar sensor not located at or near the airfield would almost certainly degrade accuracy to unacceptable levels. We have not calculated the actual error level for this report, since it would be highly dependent on specific airfield and sensor placement.

An additional concern is that, according to controllers at Toronto ACC, it is not obvious to an operating controller that an off-airfield sensor is providing position information to his or her display. We could find nothing in the RAMP specifications to contradict this statement. Thus, the controller may be unknowingly using information that is of less than suitable accuracy when monitoring simultaneous independent parallel ILS approaches.

We strongly recommend that the RAMP System only display position information from on-airfield sensors to controllers monitoring simultaneous independent parallel ILS approaches.

4.2 OTHER AREAS

Several additional areas of improvement should be considered for Canadian standards for simultaneous independent parallel ILS approaches. Although each of the following areas is important, they are of lesser concern than the two areas mentioned above.

The first area for improvement is investigation of obstacles located off the final approach course in the event an aircraft is broken out from a simultaneous independent parallel ILS approach below the minimum vectoring altitude (MVA). Normal obstruction clearance requirements for instrument approaches do not protect the significant turn from final

approach that might be expected if an aircraft were broken out due to a deviation by an aircraft on an adjacent approach. The FAA has developed draft standards for Obstacle Assessment Surfaces for simultaneous independent parallel ILS approaches and has performed obstacle evaluations at a number of airports. We recommend that Canada adopt such Obstacle Assessment Surfaces for runways where simultaneous independent parallel ILS approaches are conducted.

In the event of a deviation by an aircraft on a simultaneous independent parallel ILS approach, prompt action by ATC and aircrews may be necessary to avert a collision. Extensive testing has shown that controller detection and reaction to a deviation generally varies by only a few seconds. Pilot reaction can be more variable, however (FAA, 1991b). Testing has shown that simple awareness training for pilots conducting simultaneous independent parallel ILS approaches can significantly reduce the occurrence of long response times to controller instructions (Jones, 1992). An additional concern is that the response to controller instructions by newer highly-automated aircraft has been persistently slow during recent testing of simultaneous independent parallel ILS approaches by the FAA, despite awareness training. Testing is ongoing at this time to determine the origin of the slowness and to develop recommended training routines and documentation to overcome it. We recommend that Canada review the FAA testing, when complete, and consider adopting requirements for training of aircrews and/or documentation on conducting simultaneous independent parallel ILS approaches. For Phase I of this study, we are assuming the faster aircrew performance documented in Jones (1992). This assumption may have to be modified for future testing and evaluation, depending on the outcome of current FAA testing of pilot responses.

Specific phraseology is contained in a number of areas in the ATC MANOPS, but not for simultaneous independent parallel ILS approaches--particularly for phraseology used to expedite the breakout of aircraft threatened by a deviation or to return a deviating aircraft to course. We recommend that such phraseology be added to the ATC MANOPS, such as contained in FAA and ICAO documents (FAA, 1992a; ICAO, 1985).

As discussed earlier, radar system performance is an important factor in monitoring simultaneous independent parallel ILS approaches. The type of radar system, or relevant specifications of the radar system, should be specified in standards to ensure appropriate systems are used for monitoring.

Since accuracy typically degrades with increasing distance, we also recommend that Canadian standards incorporate limitations on the distance aircraft can be from radar sensors during simultaneous independent parallel ILS approaches. For example, assuming the sensor is at the airport, the maximum distance from the threshold at which aircraft lose 1000 ft vertical separation should be restricted. In this analysis, we have assumed a maximum distance of approximately 14 nautical miles (which corresponds to an altitude of approximately 4500 ft above the threshold as tested at the FAATC) and recommend this as a maximum distance when conducting simultaneous independent parallel ILS approaches at the minimum spacings recommended in this report. These limitations should also reduce the frequency of nuisance breakouts, since TNSE increases with distance from the ILS localizer antenna. Also, siting sensors between parallel runways should be encouraged.

We recommend that Transport Canada include resolution of blunders in initial and recurrent training for all controllers who monitor simultaneous independent parallel ILS approaches.

Simultaneous transmissions are a continual difficulty in busy ATC environments. Normally they are only a nuisance, but conflicting transmissions have been implicated in a number of accidents and incidents (e.g., the collision between two Boeing 747s at Tenerife in 1977). Testing has shown that conflicting transmissions can also be a factor in simultaneous independent parallel ILS approaches. Anti-blocking devices (ABDs), which inhibit transmissions when a frequency is busy, are available commercially and are presently being

tested by the FAA. We recommend Transport Canada consider the use of ABDs during simultaneous independent parallel ILS approaches, assuming the successful completion of testing by the FAA.

Incorporation of the above recommendations, particularly those in Section 4.1, should make Canadian procedures superior to those tested during US simultaneous independent parallel ILS approach procedure development.

4.3 SUMMARY

In summary, we recommend that:

- Canadian procedures for simultaneous independent parallel ILS approaches be modified to require that one monitor controller be used for each runway. Each monitor controller should have a separate discrete frequency with tower-override capability.
- Only position information from on-airfield sensors be displayed to controllers monitoring simultaneous independent parallel ILS approaches.
- Obstacle Assessment Surfaces be adopted for runways where simultaneous independent parallel ILS approaches are conducted.
- FAA testing of pilot reactions, when complete, should be reviewed. Requirements for training of aircrews and/or publishing documentation for aircrews conducting simultaneous independent parallel ILS approaches should be considered for adoption.
- Phraseology used to expedite the breakout of aircraft threatened by a deviation or to return a deviating aircraft to course be added to the ATC MANOPS.
- The type of radar system, or relevant specifications of the radar system, be specified for simultaneous independent parallel ILS approaches.
- Limitations be placed on the distance of the GSI from the radar sensor during simultaneous independent parallel ILS approaches.
- Training in resolution of blunders be included in initial and recurrent training for monitor controllers.
- The use of ABDs during simultaneous independent parallel ILS approaches be considered.





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SECTION 5.

ANALYSIS OF CANADIAN SIMULTANEOUS APPROACH STANDARDS USING THE RAMP RADAR AND DISPLAY SYSTEM AND THE CAATS

In this section we will attempt to correlate testing and evaluation conducted by the FAA using US procedures and equipment with Canadian procedures and equipment to assess the potential for reduction of minimum runway spacing requirements during simultaneous independent parallel ILS approaches using the RAMP Radar and Display System and the CAATS with the RAMP Radar.

5.1 ASSUMPTIONS

- One monitor controller with a discrete frequency and override capability will be used for each runway during simultaneous independent parallel ILS approaches
- Only data from on-airfield radar sensors will be displayed to monitor controllers
- The RAMP Radar and Display System with specifications and performance discussed in Section 3 is used, or the CAATS is used with specifications as discussed in Section 3.
- The capacity of the RAMP processing system is sufficient for traffic levels expected in simultaneous independent parallel ILS approaches.
- Obstacles will not be a factor should aircraft be broken out from an approach below MVA.
- Appropriate standardized phraseology is used to return aircraft to course or break out endangered aircraft.
- GSI distances less than approximately 14 nmi are used.
- Performance of aircrew and aircraft flying simultaneous independent parallel ILS approaches in Canada have similar TNSE and breakout performance as pilots flying these approaches in the US (breakout performance is assumed consistent with Jones (1992)).

- Given comparable equipment, the performance and reaction times of Canadian and US controllers will be similar.
- Canadian goals for collision risk during simultaneous independent parallel approaches are similar to US goals.

5.2 ANALYSIS

Given the assumptions above, differences between Canadian ATC and pilot procedures for simultaneous independent parallel ILS approaches and those procedures tested at the FAATC are negligible. Thus, the performance of the ATC system should be dependent upon radar equipment and controller interaction with that radar equipment.

We note from Tables 3-3 and 3-4 that the overall system accuracy of the RAMP Radar and Display System, as field tested, and the CAATS, as specified, is superior to any ASR-9 system tested by the MPAP at the FAATC. In particular, it is superior to the FMA system with ASR-9 sensor as tested at 4300 ft runway spacing.

The RAMP and CAATS are considerably superior to the less accurate ARTS/ASR-9 systems tested at 4300 and 5000 ft runway spacing. FAATC testing of simultaneous independent parallel ILS approaches indicated that 5000 ft spacing was acceptable (FAA, 1992b) and 4300 ft spacing (FAA, 1991c) was not when using the ARTS/ASR-9 combination.

Although specifications for surveillance delays are higher for the RAMP Radar and Display System than the ARTS/ASR-9, observed system delays appear comparable or better than both ASR-9 configurations tested. Based on these accuracy and delay figures, it would appear that the RAMP or CAATS would certainly be suitable at 5000 ft, where the ARTS/ASR-9 was satisfactory, and may be suitable at spacings as low as 4300 ft, where the FMA/ASR-9 combination was satisfactory.

The FMA has several features not contained in the current RAMP or CAATS displays, however. The cross-track scale of the FMA is expanded at a 4.4:1 ratio to the along-track scale. While this feature still does not improve FMA position accuracy to better than the level estimated for the RAMP, it may affect controller perception of deviations. Also, the FMA contains alert features that change the color of aircraft symbols approaching or penetrating the NTZ, and these alerts may improve controller performance.

Unfortunately, there has been no study quantifying the effects of the expanded scale or the alerts versus the improved display and system accuracy of the FMA. Measurements have been made that indicate that the average controller response time is about 3 seconds faster on the FMA display than the ARTS display when both use position information from an ASR-9 sensor (SRC, 1995), but it is unknown if this improvement is due to the FMA's more accurate display, expanded cross-track scale, alerts, or to some combination of the three.

If the improvement in response time is due primarily to the improved accuracy of the FMA, then one might expect that controller performance using the RAMP or CAATS could be comparable to or better than the FMA with the ASR-9. If the improvement in response time is due primarily to the cross-track scale or the alerts, then controllers using the RAMP or CAATS may not equal the performance of controllers using the FMA. In either case, controller performance using the RAMP or CAATS system should be substantially better than controllers using the ARTS/ASR-9 system, which has less accuracy and no alerts or expanded cross-track scales.

Based on observations of numerous simulations of simultaneous independent parallel ILS approaches, we believe that the controller performance using either the RAMP or CAATS

systems will be substantially better than using the ARTS/ASR-9 systems tested at the FAATC and may equal the performance of controllers using the FMA with an ASR-9 sensor. Given the assumptions stated in Section 5.1, we therefore believe that the RAMP or CAATS system is suitable for simultaneous independent parallel ILS approaches to runways spaced as close as 5000 ft apart and has the potential to allow simultaneous independent parallel ILS approaches to runways spaced as close as 4300 ft.

As discussed earlier, we have noted little difference in controller performance during dual and triple simultaneous independent parallel ILS approaches. Accordingly, we believe that the RAMP and CAATS systems also are suitable for simultaneous independent parallel ILS approaches to three runways spaced as close as 5000 ft apart and have the potential for simultaneous independent parallel ILS approaches to three runways spaced as close as 4300 ft.

Further human factors testing is required to determine and verify the adequacy of runway spacings below 5000 ft.





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SECTION 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Canadian standards for simultaneous independent parallel ILS approaches are generally quite satisfactory. As discussed in Section 4, however, there are several improvements that need to be incorporated, notably the use of one monitor controller for each runway and the exclusive display of on-airport sensor information to the controller.

The RAMP Radar and Display System is an extremely capable system and is suitable for conducting simultaneous independent parallel ILS approaches. The observed performance of the system is better than US systems using the ASR-9 tested at the FAATC for simultaneous independent parallel ILS approaches.

Given the assumptions stated in Section 5.1, the RAMP Radar and Display System, or the CAATS used with the RAMP sensor, is suitable for simultaneous independent parallel ILS approaches to two or three runways spaced at least 5000 ft (1525m) apart.

Given the assumptions stated in Section 5.1, we believe that the RAMP Radar and Display System, or the CAATS used with the RAMP sensor, has the potential to allow simultaneous independent parallel ILS approaches to two or three runways spaced as close as 4300 ft (1310m). Further testing will be required prior to implementation.

6.2 RECOMMENDATIONS

The recommended changes to Canadian ATC procedures for simultaneous independent parallel ILS approaches contained in Section 4 should be implemented.

Transport Canada should determine if a need exists for simultaneous independent parallel ILS approaches to two or three runways spaced closer than 5000 ft. If these capabilities are desired, then testing should be accomplished to determine the appropriate runway spacing for approval. This testing would involve gathering controller reaction times for several runway spacings (e.g., 4300 and 5000 ft) in a real-time human factors simulation. Then, using Monte Carlo simulation, the runway spacing at which acceptable levels of safety are reached could be estimated. Appendix C contains an outline of a suggested test.

Should closer runway spacings or triple approaches be desired but determined to be

infeasible by testing of the RAMP or CAATS system, Transport Canada should consider the following options:

- Modify the RAMP Radar and Display System to include expanded scales and alert functions similar to the FMA. This option would probably require further testing to insure that controller performance was equal to performance when using an FMA.
- Modify the CAATS to include expanded scales and alert functions similar to the FMA. If performance were equal to or better than the FMA, then standards with reduced runway spacing could be implemented based on US testing, if desired.
- Consider purchasing commercial FMAs and using position input from the RAMP Radar to feed the FMA. The expanded scale and alerts are implemented in the FMA. Standards with reduced runway spacing could be implemented based on US testing, if desired.

